BEDROCK GROUNDWATER FLOW MODEL

The bedrock groundwater flow model was constructed using Flowpath II Version 1.0, a two-dimensional, finite-difference ground-water flow model (Waterloo Hydrogeologic, of Ontario, Canada). Conceptually, the model was set up as a slab of unit thickness intended to represent a vertical section through the overburden and bedrock aquifers in the vicinity of the site. This approach was used to simplify the hydrogeologic problem, yet determine whether pumping at domestic wells located northwest of the site and Charleston Creek is likely to capture contaminated ground water from the overburden aquifer at the site.

The location of the model cross-section line is approximately 500 feet to the east of the site to better represent the hydrogeology in the vicinity of the supply wells, and extends 4,200 feet across two topographic highs present north and south of the site (see Figure 1 in this appendix). Vertically, the cross-section extends from an elevation of 900 to 1,800 feet above mean sea level (ft msl); land surface elevations along the cross-section line were determined from USGS topographic maps. On-site soil borings logs were used to construct a conceptual model of the hydrogeology of the sediment wedge encountered below the site. A thin layer of overburden was assumed to be present over the bedrock aquifer in the lower portions of the valley cross-section.

Charleston Creek in the area adjacent to the site is located at an elevation of roughly 1320 ft msl, and the bedrock aquifer below the creek location is modeled to a depth of approximately 400 feet (to an elevation of 900 ft msl). Water levels measured at on-site shallow and deep overburden wells and piezometers indicate that an upward vertical gradient exists within the overburden aquifer in the vicinity of the creek (see Section 3.3 of the RFI Report), confirming that the creek is a local ground water discharge boundary.

The model uses 237 columns and 209 rows. The hydrogeologic system is approximated by a slab of unit thickness bounded on all sides by *inactive cells*; these cells are colored blue-purple on the figures of the model (see Appendix H). Within these *inactive cells*, the model consists of a bedrock aquifer, an overburden aquifer, four pumping wells, and Charleston Creek. Figure 2 in this appendix shows the entire model input parameter zones; Figure 3 in this appendix is a smaller scale view of the model.

A single row of *specified flux boundary cells* are used along the entire border at the "top" of the model (representing the ground surface) to input precipitation acting to recharge the aquifers; these cells are colored blue. The flux was set to input 10.2 inches of rain per year, equivalent to 25 percent of the yearly precipitation known to occur in this region (refer to Section 3.5 of the RFI Report). A precipitation value of 10.2 inches per year corresponds to an input of 0.0174 gpd/ft^2; since the model surface area is equal to 4,200 ft^2, the global water balance into the system is 9.75 cubic feet (ft^3). All water flowing through the flux cells either discharges to the creek or to the wells, if these are pumping. Charleston Creek consists of a single *lake/river cell* with a leakage factor of 0.05.

The bedrock aquifer forms the largest model zone. Immediately beneath the site, it occurs beneath the overburden at depths of up to 60 to 70 feet below ground surface (ft bgs). On figures illustrating the model inputs in this appendix, the bedrock aquifer zone is not colored and appears as the white area that makes up the majority of the model area. Bedrock transmissivity was estimated using the hydrogeologic data for wells designated X0943 and X0300 (see Figure 7 of the RFI Report); no data is available for the water supply waiver lcations designated as 39, 40 and 41. The data for wells X0943 and X0300 were used to calculate a specific capacity value for each well, which was then used to estimate the aquifer transmissivity. The specific capacity of each well was estimated by assuming that the drawdown from pumping at each well is equal the total well depth minus 40 feet; the 40 foot value represents the sum of an assumed static depth to water of 10 feet, and a pumping water level that is 30 feet above the well bottom. Using this approach, drawdowns of 117 and 79 feet were determined for wells X0943 and X0300, respectively. The specific capacity was then determined by dividing the reported well yield (of 6 and 8 gpm, respectively) by the drawdown; values of 0.051 and 0.10 gpm/ft of drawdown were thus calculated for well X0943 and X0942, respectively.

The bedrock transmissivity was calculated using the empirical equation used to relate specific capacity to transmissivity[1]. Transmissivities of 102 and 203 gpd/ft^2 were determined for wells X0943 and X0942, respectively. Hydraulic conductivity (K) values of 0.12 and 0.85 ft/d were then determined for these wells by dividing the calculated transmissivities by the reported open hole length for each well. Finally, a geometric mean of 0.32 ft/d was calculated for the bedrock aquifer using the two values discussed above, and this value was assumed to be representative of the horizontal hydraulic conductivity for the bedrock aquifer. The vertical bedrock hydraulic conductivity was assumed to be one tenth the horizontal value, or 0.032 ft/d.

The overburden aquifer was input as a layer whose thickness increases from approximately 10 feet below the Charleston Creek to a depth of approximately 60 to 70 feet below the southern portion of the site. The overburden thins and is assumed to be absent at the higher elevations of the model where the topography is steeper, and the water table probably occurs within the bedrock. The overburden is colored orange on figures included in this appendix.

The overburden aquifer hydraulic conductivity of 23 ft/d determined from the 48-hour constant rate pumping test (see Section 3.3.2 of the RFI Report) was used as the horizontal hydraulic conductivity of the entire overburden zone. The vertical hydraulic conductivity was assumed to be one tenth that value, or 2.3 ft/d. This conductivity

[1] See Appendix 16.D in Driscoll, 1986

value is representative of glaciofluvial deposits, which are present immediately below the site. This conductivity was used for all overburden deposits, although the thinner sediment layer that overlies bedrock farther from the valley bottom probably has significantly lower permeability.

The four domestic wells/water supply waivers were represented by inputting a *pumping well cell* at each node that represents the open hole at each well. The open-hole interval for well X0943 was set to 115 to 157 ft bgs. No construction details are known for wells assumed to exist at water supply waivers 39, 40 and 41. Based on data summarized on Table 2.2 of the Existing Conditions Report, wells in the region are installed to depths of up to approximately 200 to 300 feet. Since domestic wells tend to be shallow, the open-hole interval of the wells assumed to exist at water supply waiver locations 39, 40 and 41 were assumed to extend from 100 to 200 ft bgs. During the sensitivity analysis performed as part of the modeling effort, additional runs were performed using open-hole intervals assumed to be either 50 to 100 or 200 to 300 ft bgs.

The four domestic wells were assumed to pump 250 gpd each, the typical demand of a domestic well. However, since the model only represents a 1-foot thick slice through the bedrock aquifer, only a small portion of the aquifer that supplies water to each well is included within the model domain. Therefore, the pumping rate for each domestic well was modified and was scaled for the model in the following manner. A capture zone analysis was performed to determine the distance to the downgradient stagnation point of a well installed in bedrock with a hydraulic conductivity of 0.32 ft/d and a gradient of 0.022 (the gradient established in the modeled bedrock under static conditions). Since the aquifer in the vicinity of the wells is approximately 500 feet, a transmissivity of 160 ft^2/d was used for the bedrock aquifer. This value was adjusted for partial penetration effects, and only 20 percent (100-foot open hole/500-foot bedrock aquifer) of the bedrock transmissivity was used to calculate the stagnation point, which was calculated to be 7.5 feet downgradient of the well. A series of simulations performed using a single well being pumped at various rates determined that a pumping rate of 8 gpd in the model slice would approximate the point of stagnation induced by the pumping of 250 gpd within a laterally extensive aquifer. This approach is conservative because the point of stagnation of the well is used, in the model, to calibrate a trench of unlimited lateral extent, where every cross section has the same point of stagnation distance.

Numerical simulations were run using the solver Preconditioned Conjugate-Gradient (PCG) method. Table 1 in this appendix provides a summary of the input parameters for the static and pumping simulations, as well as for runs performed as part of the sensitivity analysis.

A simulation was initially performed using the inputs described above and no pumping at the domestic wells; this run illustrates static conditions. The steady-state flow configuration is illustrated using a combination of contour lines and particle path lines. The contrast in permeability between the bedrock and overburden aquifers diverts flow within the deeper bedrock to the more permeable overburden wedge located south of the creek prior to discharging to the creek (see Figures 4 and 5 in this appendix). In the model, 9.75 ft^3/d of water enters the model along the unit cross-section via flux cells, and all of it is discharged to the creek. The global water balance for the static simulation had a total mass balance error of 0.046 percent.

A simulation was then run with the four domestic wells pumping the equivalent of 1,000 gpd of groundwater. As shown in Figures 6 and 7 in this appendix, the run results indicate that none of the water within the overburden aquifer flows into the bedrock aquifer below the creek, and no groundwater in the overburden aquifer beneath the site reaches any of the domestic wells. Although water within the bedrock aquifer below the site at depths of 150 to 250 ft bgs is shown to migrate below the creek and flow to the domestic well located closest to the creek, this water represents recharge to the bedrock that originates at ground surface at distances approximately 1,400 to 1,500 feet south of the site.

In the pumping simulation described above, *dry cells* formed in the immediate vicinity of the two wells located closest to the creek. These dry cells are an artifact of the manner in which the solver calculates the water input/output in individual cells during the iteration process; these were produced due to the combination of the low bedrock transmissivity and a pumping rate that significantly stresses the bedrock aquifer, even though the simulations were run as a "confined aquifer". During the pumping simulation, 9.75 ft^3/d of water enters the model via *flux cells*, 4.27 ft^3/d is removed by the four pumping wells, and 5.49 ft^3/d is discharged to the creek. The global water balance for the simulation had a total mass balance error of 0.0027 percent.

A sensitivity analysis performed on the model demonstrated that the model is insensitive to changes in the domestic well open-hole depths, the bedrock hydraulic conductivity, and to a reduction in the bedrock aquifer thickness. The sensitivity of the model to changes in the domestic well open hole interval depth was determined by changing the open hole interval of the two wells located closest to the creek (water supply waivers 39 and 40); open hole intervals were first set to a depth of 50 to 100 ft bgs, and on a subsequent run these were set to a depth of 200 to 300 ft bgs. The results of these simulations showed that the depth of the underflow at the creek and overall ground water flow patterns were essentially unchanged.

The sensitivity of the model to changes in the bedrock transmissivity value was determined by performing simulations where the bedrock horizontal and vertical hydraulic conductivities were increased or decreased by an order of magnitude. Decreasing the bedrock hydraulic conductivity values led to the formation of a large area of *dry cells* around the pumping wells, whereas increasing the conductivity increased the depth at which flow beneath the creek occurs. Decreasing the thickness of the bedrock aquifer by 100 feet had little effect on the ground water flow patterns in the bedrock aquifer. In all cases, flow lines that would flow under the creek correspond to recharge that entered the aquifer far upgradient of the site.

Despite the extremely conservative nature of the model, the results indicate that no groundwater recharging the site and encountering the impacted area could be captured by any of the wells that were simulated.

Table 1
Model Input Variables

Osram Sylvania Products, Inc.
Wellsboro, Pennsylvania

Input Variables	Modeling Run Designation					
	static	pumping	pumping *deep open hole*	pumping *shallow open hole*	pumping *decreased bedrock K*	~~pumping~~ *Incraesed bedrock K*
Overburden Aquifer Hydrogeologic Properties (model property no. 1)						
Hydraulic Conductivity $K_{x\ (ft/day)}$	23.0	23.0	23.0	23.0	23.0	23.0
Hydraulic Conductivity $K_{y\ (ft/day)}$	2.3	2.3	2.3	2.3	2.3	2.3
Bedrock Aquifer Hydrogeologic Properties (model property no. 2)						
Hydraulic Conductivity $K_{x\ (ft/day)}$	0.32	0.32	0.32	0.32	**0.032**	**3.2**
Hydraulic Conductivity $K_{y\ (ft/day)}$	0.032	0.032	0.032	0.032	**0.0032**	**0.32**
Aquifer Elevations (ft)						
Top	1.0	1.0	1.0	1.0	1.0	1.0
Bottom	0.0	0.0	0.0	0.0	0.0	0.0
Boundaries						
Flux (gpd/ft^2) (1)	0.01742	0.01742	0.01742	0.01742	0.01742	0.01742
River						
Surface Elevation (ft)	1.0	1.0	1.0	1.0	1.0	1.0
Bed Elevation (ft)	0.0	0.0	0.0	0.0	0.0	0.0
Leakage Factor	0.05	0.05	0.05	0.05	0.05	0.05
Domestic Well Data						
Well X0943						
Open Hole Interval (ft bgs)	115 to 157	115 to 157	115 to 157	115 to 157	115 to 157	115 to 157
Pumping Rate (gpd)	0	250	250	250	250	250
Well 30						
Open Hole Interval (ft bgs)	100 to 200	100 to 200	100 to 200	100 to 200	100 to 200	100 to 200
Pumping Rate (gpd)	0	250	250	250	250	250
Well 40						
Open Hole Interval (ft bgs)	100 to 200	100 to 200	**200 to 300**	**50 to 100**	100 to 200	100 to 200
Pumping Rate (gpd)	0	250	250	250	250	250
Well 41						
Open Hole Interval (ft bgs)	100 to 200	100 to 200	**200 to 300**	**50 to 100**	100 to 200	100 to 200
Pumping Rate (gpd)	0	250	250	250	250	250
Total pumping rate (gpd)	0	1,000	1,000	1,000	1,000	1,000
Total pumping rate (ft^3/day)	0	133.7	133.7	133.7	133.7	133.7

Notes:

(1) Specified Flux boundary set at top of model domain to mimic 10 inches precipitation per year.

(2) Bold numbers used to indicate changed input parameters.

Table 2
OSRAM SYLVANIA PRODUCTS INC.
WELLSBORO, PENNSYLVANIA

Summary of Arsenic Stream Loading Calculations

Hydrogeologic Variables	
Hydraulic Conductivity K =	23 ft/day
Hydraulic Gradient i =	0.017
Plume depth z =	4.0 ft
Plume width - Zone 1 =	200 ft
Plume width - Zone 2 =	140 ft
Plume width - Zone 3 =	140 ft
Arsenic concentration - Zone 1 =	0.204 mg/L
Arsenic concentration - Zone 2 =	0.120 mg/L
Arsenic concentration - Zone 3 =	0.061 mg/L
Stream Flow =	215 gpm

Calculations

Area - Zone 1 =	800 ft^2
Area - Zone 2 =	560 ft^2
Area - Zone 3 =	560 ft^2

Discharge to stream Q_{gw} = K * i * A

Discharge - Zone 1 =	312.8 ft^3/day	=	2339.7 gpd	=	1.625 gpm	=	0.1025 L/s
Discharge - Zone 2 =	219 ft^3/day	=	1637.8 gpd	=	1.137 gpm	=	0.0718 L/s
Discharge - Zone 3 =	219 ft^3/day	=	1637.8 gpd	=	1.137 gpm	=	0.0718 L/s
Total Discharge =	**751 ft^3/day**	=	**5615 gpd**	=	**3.90 gpm**	=	**0.246 L/s**

Arsenic Loading to Stream = Q_{gw} * Concentrations$_{gw}$

Zone 1 =	2.09E-02	mg/s
Zone 2 =	8.61E-03	mg/s
Zone 3 =	4.38E-03	mg/s
TOTAL LOADING =	**3.39E-02**	**mg/s**

0.00834

Average Arsenic Concentration of Ground Water Discharging to Stream

Concentration$_{gw}$ = 0.138 mg/L

Arsenic Concentration in Stream

Concentration$_{final}$ = (Q_{gw} * Concentration$_{gw}$) +(Q_{stream} * Concentration$_{stream}$) / Q_{gw} + Q_{stream}

Concentration$_{final}$ = 2.45E-03 mg/L

Notes: Q_{gw} *= ground water discharge from shallow overburden aquifer zone.*

Q_{stream} *= flow rate measured at stream flume.*

Concentration$_{gw}$ = ground water arsenic concentration

Concentration$_{stream}$ = stream arsenic concentration prior to loading = 0 mg/L

Concentration$_{final}$ = stream arsenic concentration with loading

gpm = gallons per minute

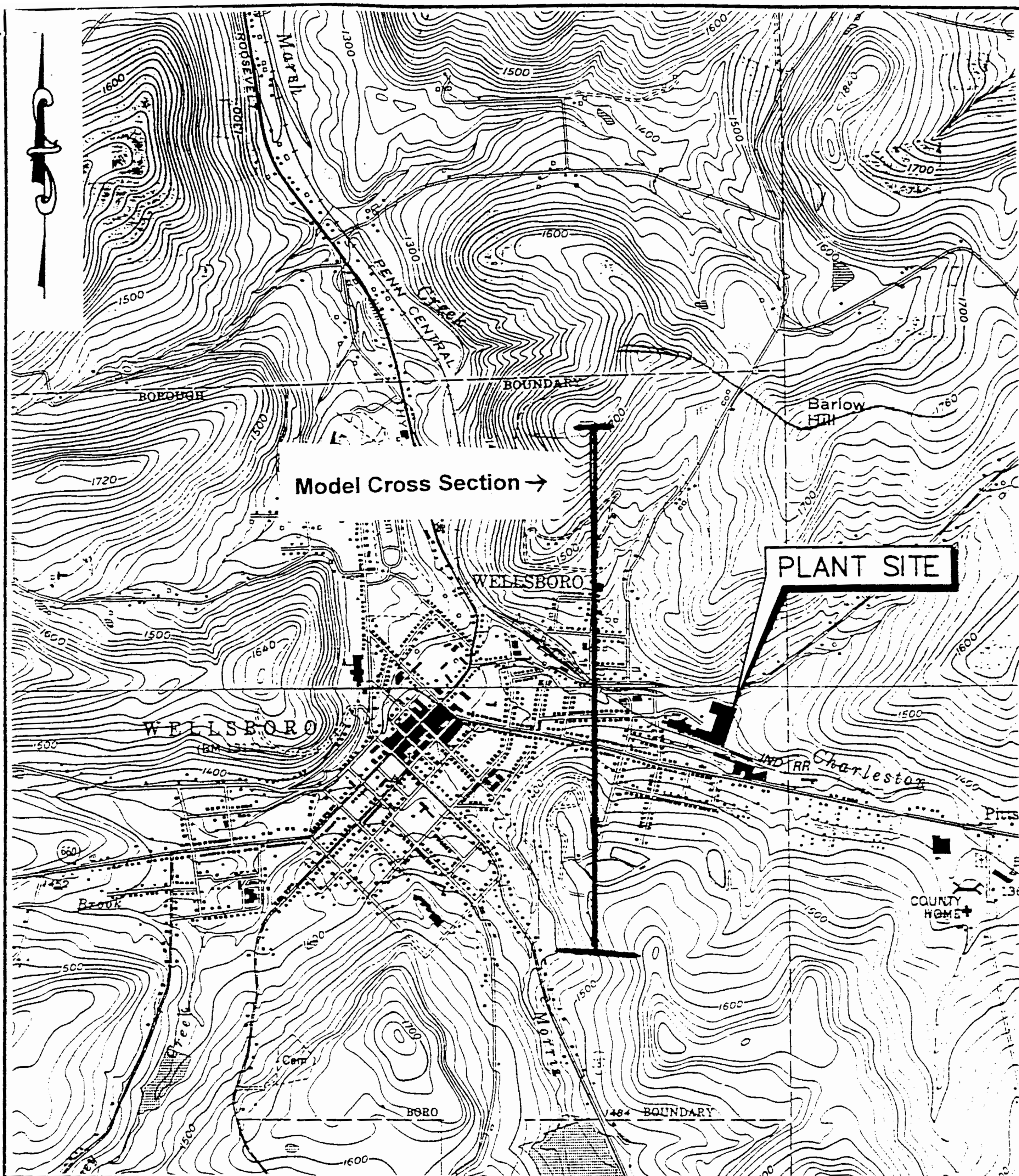


FIGURE 1

KEENEYVILLE, PA.
SE/4 ELKLAND 15' QUADRANGLE
N4145–W7715/7.5
1954
PHOTOREVISED 1969
AMS 5567 IV SE–SERIES V831

PENNSYLVANIA
QUADRANGLE LOCATION

ANTRIM, PA.
41077–F3–TF–024
1946
PHOTOREVISED 1986
DMA 5567 III NE–SERIES V831

PENNSYLVANIA
QUADRANGLE LOCATION

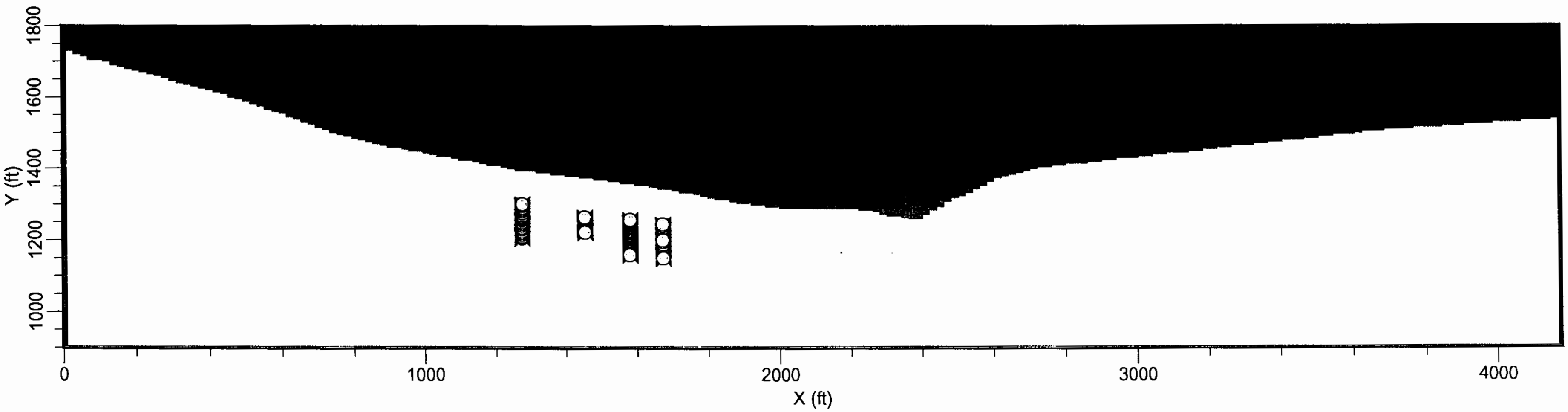
OSRAM SYLVANIA PRODUCTS INC.
WELLSBORO, PENNSYLVANIA

RCRA FACILITY INVESTIGATION

LOCATION MAP

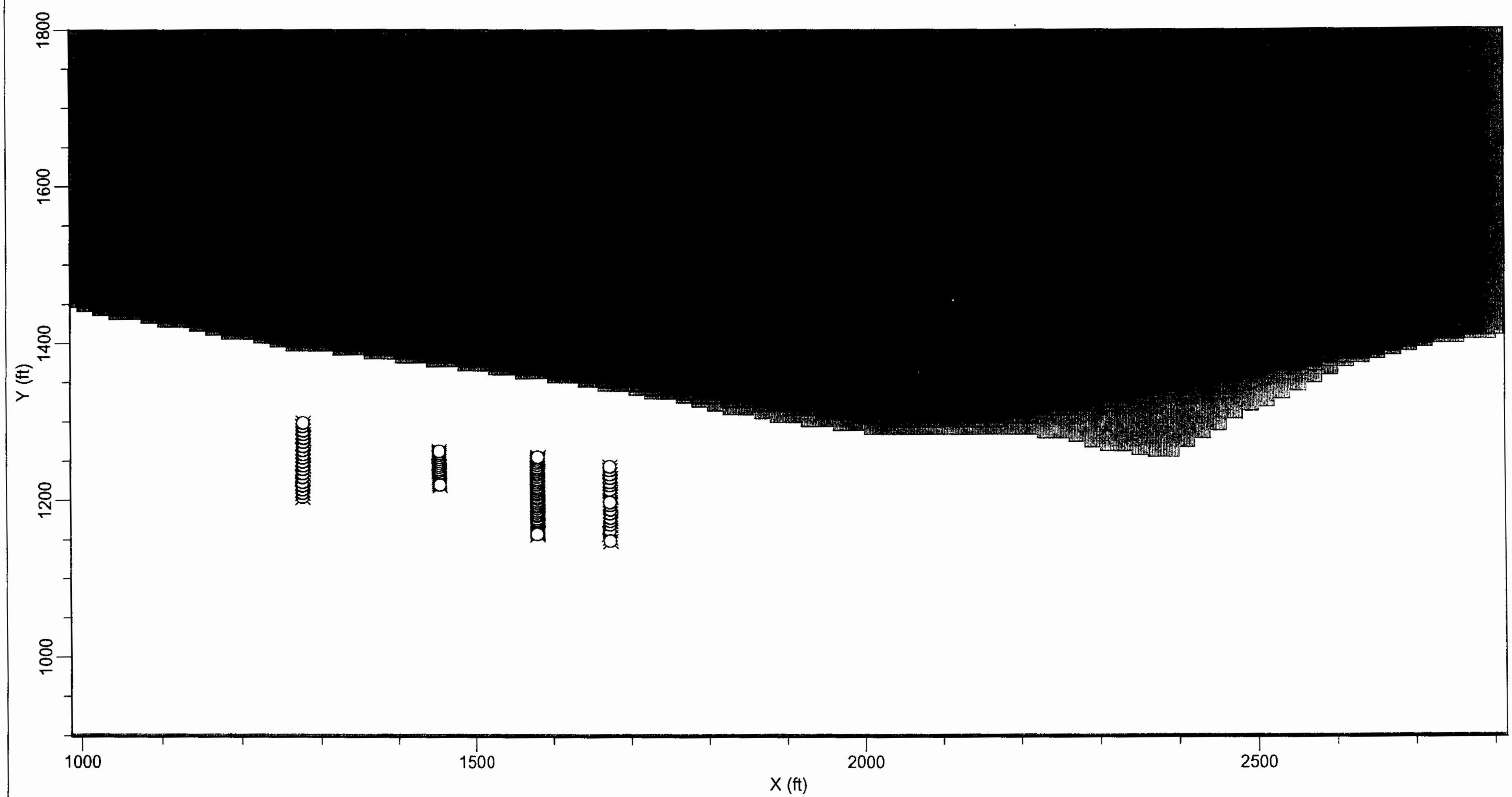
Killam
Associates ▫ Consulting Engineers

PITTSBURGH, PENNSYLVANIA

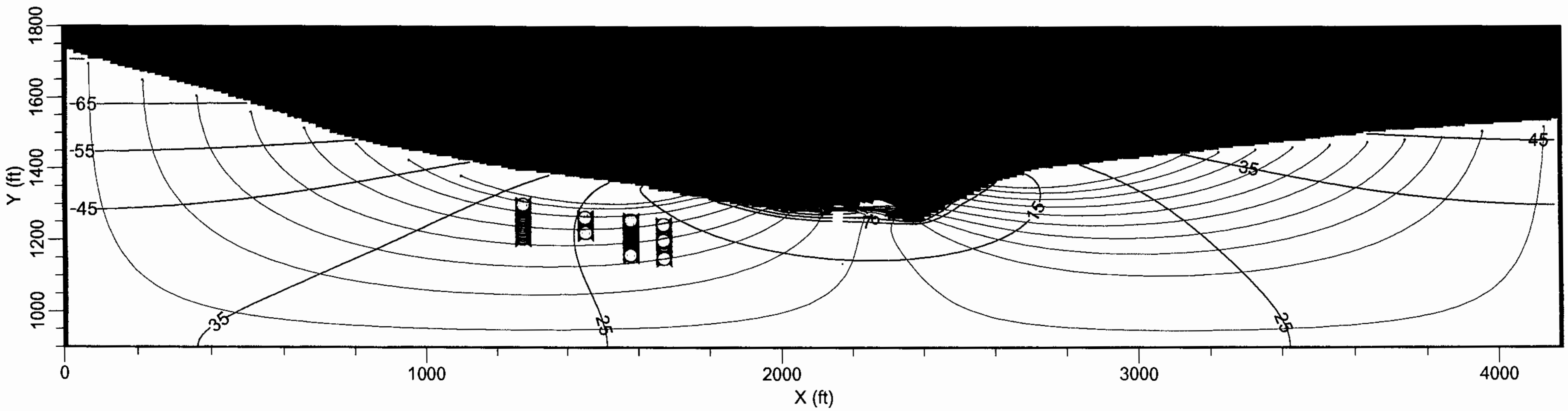


FlowPath II Ver. 1.1

Figure 2: Model Input for entire model area



FlowPath II Ver. 1.1 © 1989-1998 WHI	Figure 3: Zoom view of Model Input



FlowPath II Ver. 1.1

Figure 4: Static Conditions for entire model area

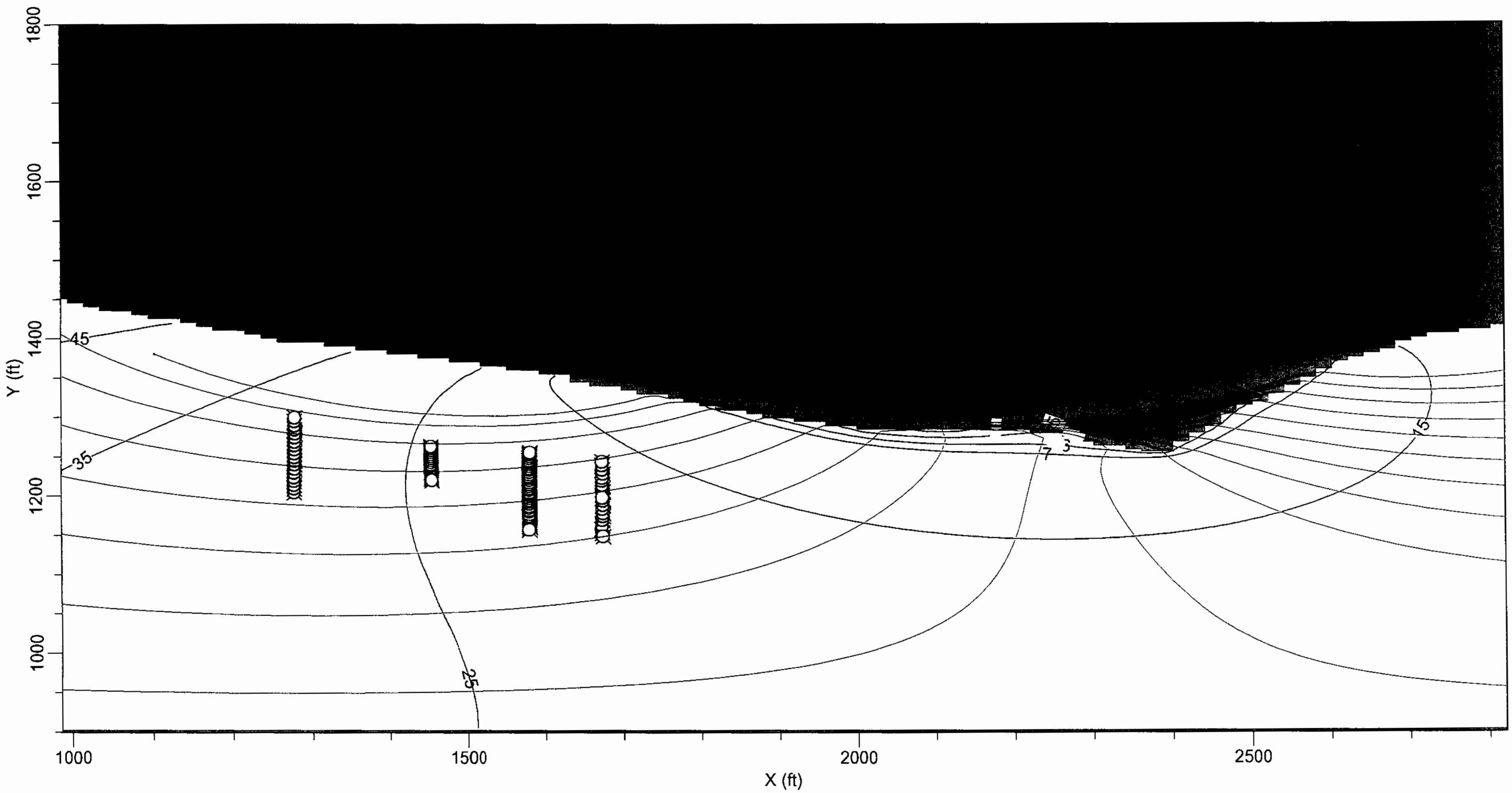


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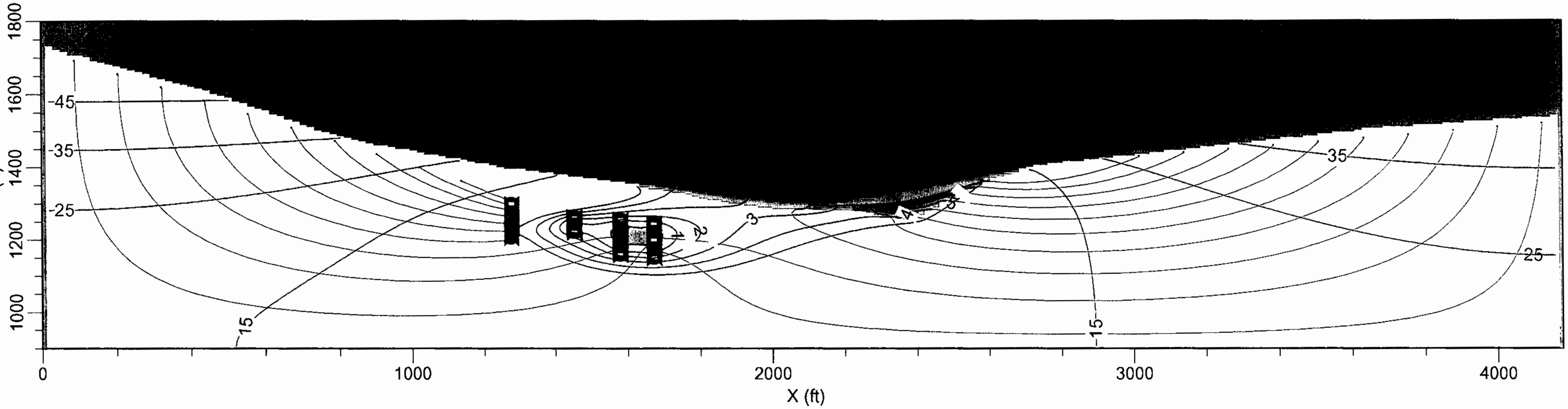
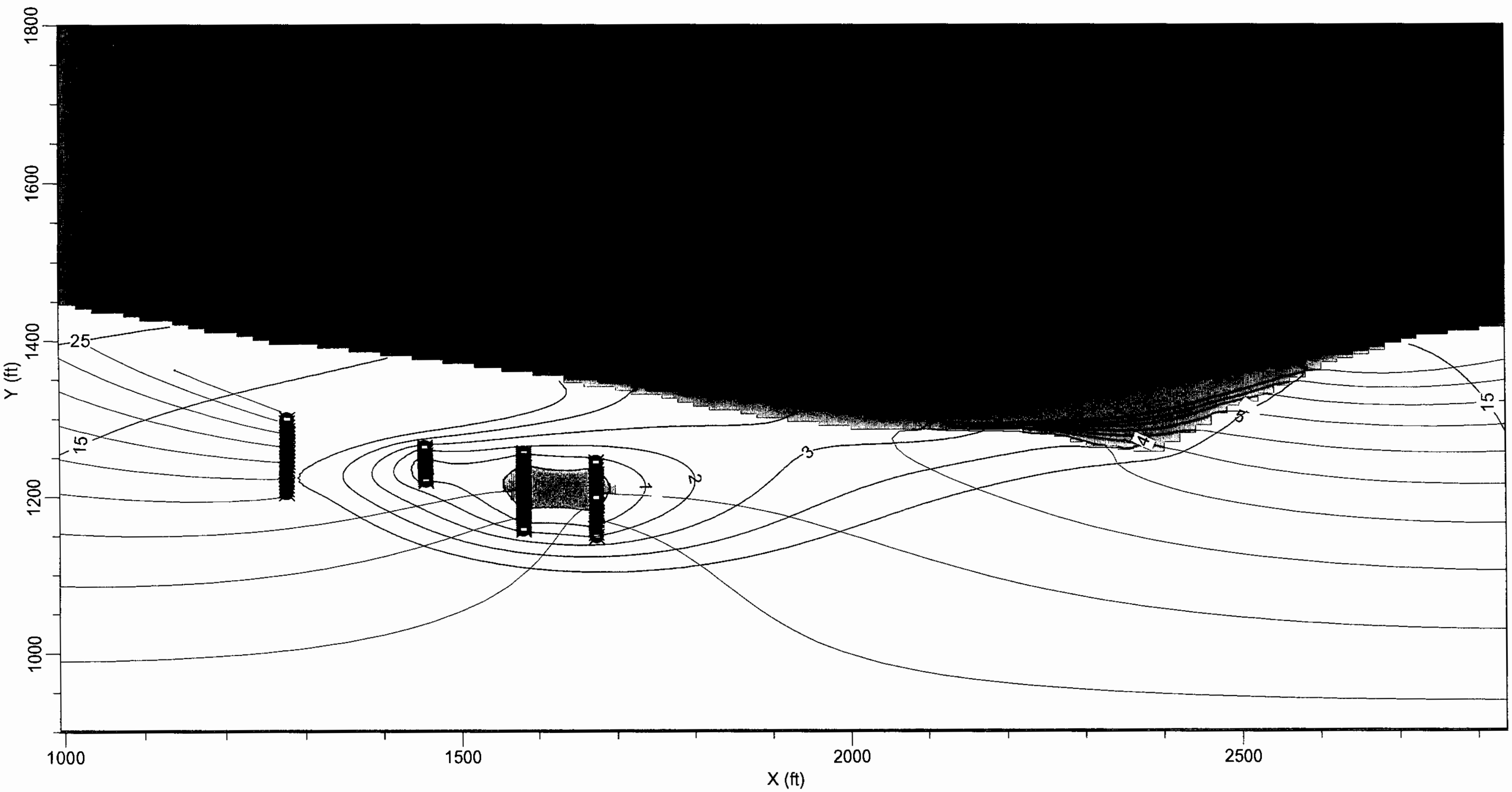
Figure 5: Zoom view of Static Conditions



FlowPath II Ver. 1.1 © 1989-1998 WHI	Figure 6: All wells pumping 250/gpd



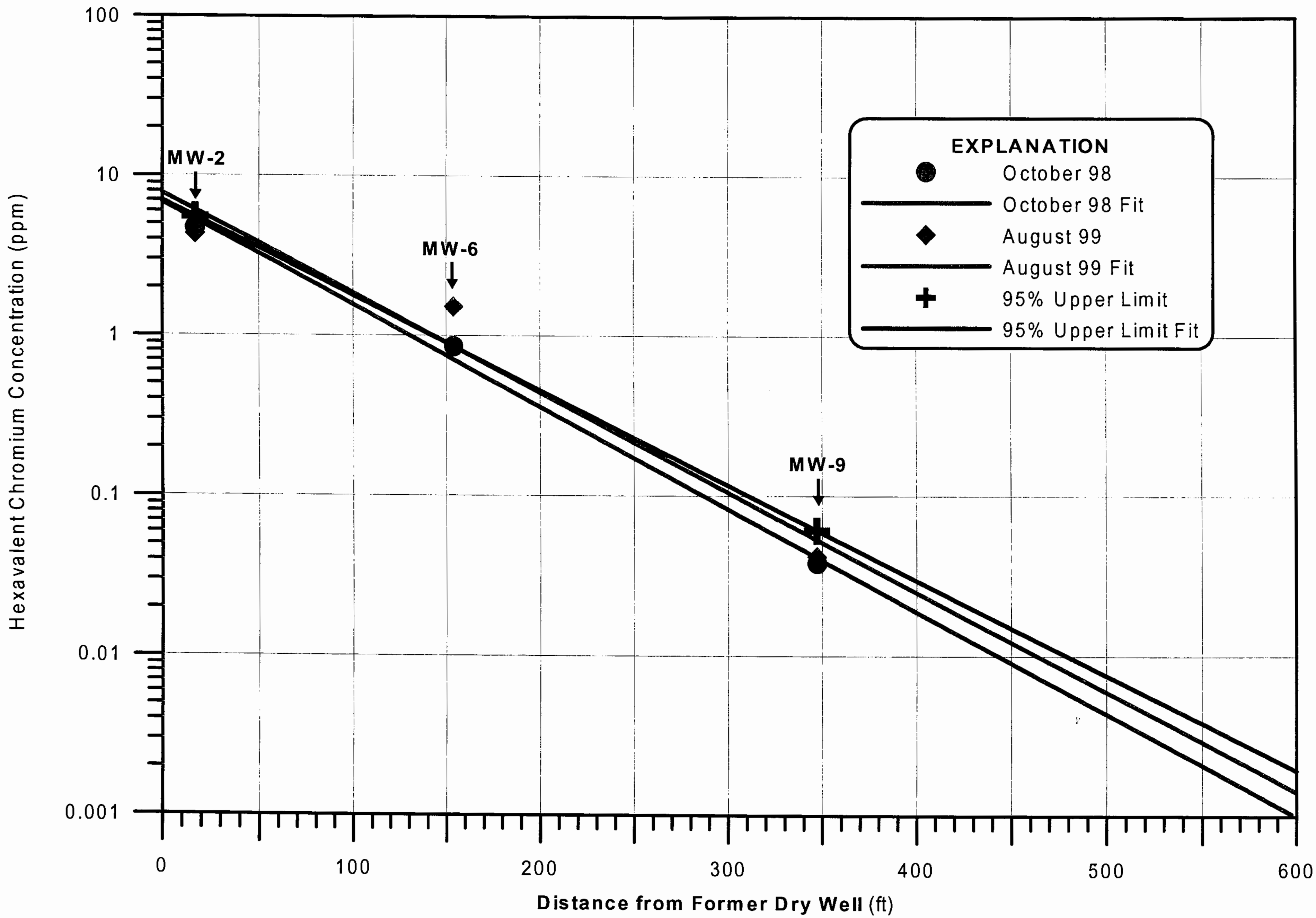
FlowPath II Ver. 1.1

Figure 7: Zoom view all wells pumping 250/gpd

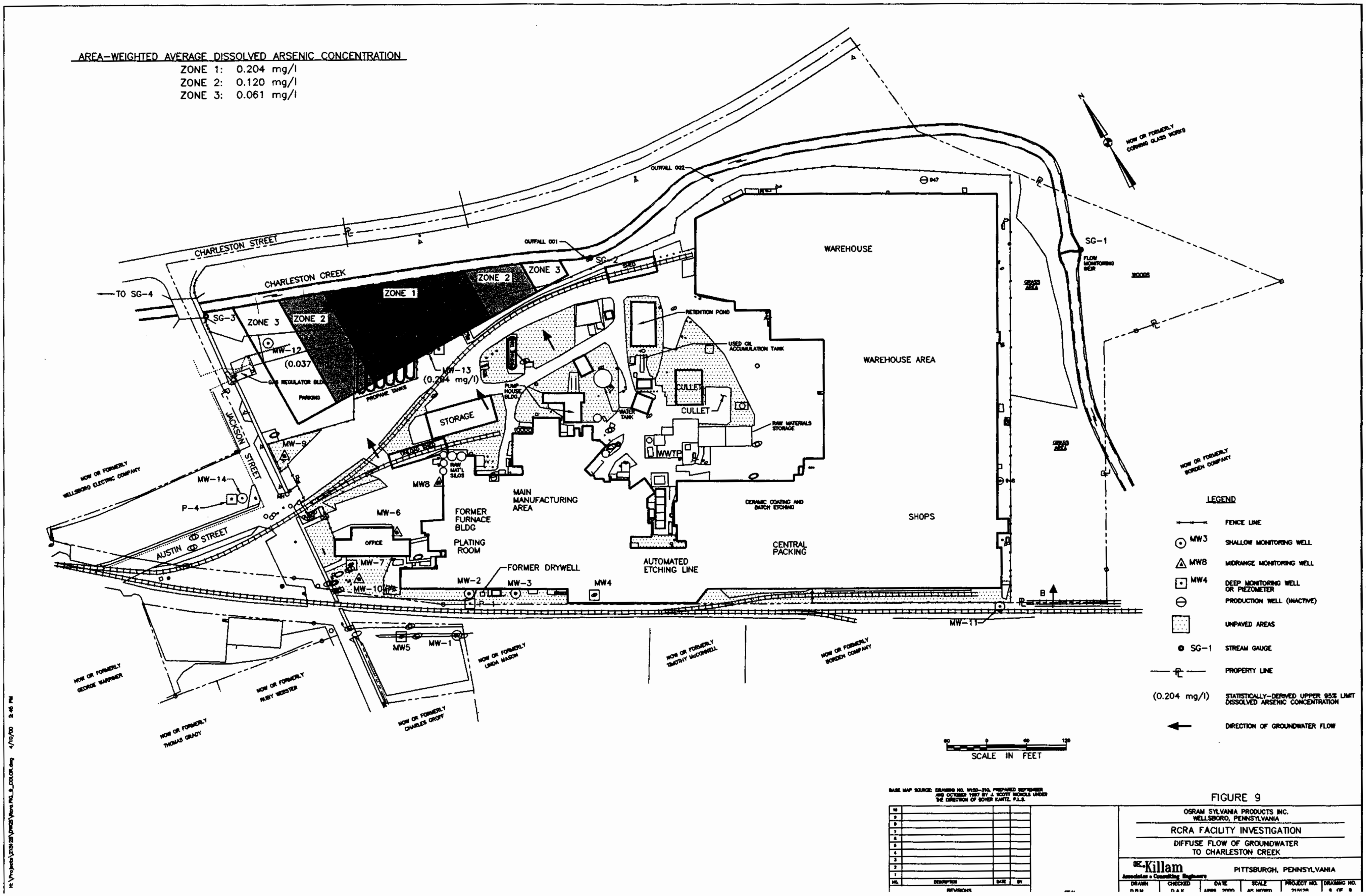
FIGUR.. ..

PLOT OF LOG HEXAVALENT CHROMIUM versus DISTANCE FROM FORMER DRY WELL

Osram Sylvania - Wellsboro, Pennsylvania



K:\eng\117525\hydro\fate & transport\hex-02.grf



AREA-WEIGHTED AVERAGE DISSOLVED ARSENIC CONCENTRATION
ZONE 1: 0.204 mg/l
ZONE 2: 0.120 mg/l
ZONE 3: 0.061 mg/l
CHARLESTON STREET
CHARLESTON CREEK
ZONE 1
ZONE 2
ZONE 3
TO SG-4
SG-3
SG-2
SG-1
OUTFALL 001
OUTFALL 002
MW-12
(0.037
MW-13
(0.204 mg/l)
STORAGE
WAREHOUSE
WAREHOUSE AREA
RETENTION POND
USED OIL ACCUMULATION TANK
CULLET
WWTP
MAIN MANUFACTURING AREA
FORMER FURNACE BLDG
PLATING ROOM
OFFICE
FORMER DRYWELL
AUTOMATED ETCHING LINE
CENTRAL PACKING
SHOPS
CERAMIC COATING AND BATCH ETCHING
RAW MATERIALS STORAGE
WATER TANK
PUMP HOUSE BLDG
RAW MAT'L SILOS
GAS REGULATOR BLDG
PARKING
PROPANE TANKS
JACKSON STREET
AUSTIN STREET
MW-1
MW-2
MW-3
MW4
MW5
MW-6
MW-7
MW8
MW-9
MW-10
MW-11
MW-14
P-4
FLOW MONITORING WEIR
WOODS
GRASS AREA
NOW OR FORMERLY CORNING GLASS WORKS
NOW OR FORMERLY BORDEN COMPANY
NOW OR FORMERLY WELLSBORO ELECTRIC COMPANY
NOW OR FORMERLY GEORGE WARRINER
NOW OR FORMERLY RUBY WEBSTER
NOW OR FORMERLY THOMAS GRADY
NOW OR FORMERLY CHARLES GROFF
NOW OR FORMERLY LINDA MASON
NOW OR FORMERLY TIMOTHY McCONNELL
LEGEND
FENCE LINE
MW3 SHALLOW MONITORING WELL
MW8 MIDRANGE MONITORING WELL
MW4 DEEP MONITORING WELL OR PIEZOMETER
PRODUCTION WELL (INACTIVE)
UNPAVED AREAS
SG-1 STREAM GAUGE
PROPERTY LINE
(0.204 mg/l) STATISTICALLY-DERIVED UPPER 95% LIMIT DISSOLVED ARSENIC CONCENTRATION
DIRECTION OF GROUNDWATER FLOW
60 0 60 120
SCALE IN FEET
FIGURE 9
OSRAM SYLVANIA PRODUCTS INC.
WELLSBORO, PENNSYLVANIA
RCRA FACILITY INVESTIGATION
DIFFUSE FLOW OF GROUNDWATER
TO CHARLESTON CREEK
Killam
Associates • Consulting Engineers
PITTSBURGH, PENNSYLVANIA
DRAWN
CHECKED
DATE
SCALE
PROJECT NO.
DRAWING NO.
NO.
DESCRIPTION
DATE
BY
REVISIONS